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VARIATION IN CANNABIS POTENCY & PRICES IN A NEWLY-LEGAL MARKET: Evidence from 30 million cannabis sales in Washington State

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Abstract

Aims—To (1) assess trends and variation in the market share of product types and potency sold in a legal cannabis retail market, and (2) estimate how potency and purchase quantity influence price variation for cannabis flower.

Design—Secondary analysis of publicly available data from Washington State's cannabis traceability system spanning July 7, 2014 to September 30, 2016. Descriptive statistics and linear regressions assessed variation and trends in cannabis product variety and potency. Hedonic regressions estimated how purchase quantity and potency influence cannabis flower price variation.

Setting—Washington State, USA.

Participants—(1) 44,482,176 million cannabis purchases, including (2) 31,052,123 cannabis flower purchases after trimming price and quantity outliers.

Measurements—Primary outcome measures were (1) monthly expenditures on cannabis, total delta-9-tetrahydrocannabinol (THC) concentration, and cannabidiol (CBD) concentration by product type; and (2) excise-tax-inclusive price per gram of cannabis flower. Key covariates for the hedonic price regressions included quantity purchased, THC, and CBD.

Findings—Traditional cannabis flowers still account for the majority of spending (66.6%), but the market share of extracts for inhalation increased by 145.8% between October 2014 and September 2016, now composing 21.2% of sales. The average THC-level for cannabis extracts is more than triple that for cannabis flowers (68.7% compared to 20.6%). For flower products, there is a statistically significant relationship between price per gram and both THC [coefficient = 0.012; 95% confidence interval (CI) = 0.011 to 0.013] and CBD [coefficient = 0.017; CI = 0.015 to 0.019]. The estimated discount elasticity is −0.06 [CI = −0.07 to −0.05].

Conclusions—In the state of Washington, USA, the legal cannabis market is currently dominated by high-THC cannabis flower, and features growing expenditures on extracts. For

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cannabis flower, both THC and CBD are associated with higher per-gram prices, and there are small but significant quantity discounts.

Keywords

Cannabis; potency; prices; legalization; drug policy; hedonic models

INTRODUCTION

Many countries have begun to liberalize cannabis policies, particularly in Europe and the Western Hemisphere. Uruguay and eight states in the US have legalized cannabis production and sale for nonmedical purposes; other jurisdictions will likely follow. In 2016, Canada appointed a federal task force to create a framework for legislation to legalize nationally. The task force's report recommended developing strategies to encourage consumption of less potent cannabis, such as price or tax schemes based on potency to discourage purchase of high-potency products [1]. Such policies might once have seemed unnecessary; advocates of legalization have long argued that prohibition drives potency up, and thus legal markets would naturally deliver safer, less-potent products (e.g., [2]). The question is more than academic, however, amidst growing concerns about the health consequences of high-potency cannabis products and the demand for them [3–6].

Discussions regarding "potency" typically concern the concentrations of delta-9-tetrahydrocannabinol (THC) or cannabidiol (CBD). Their health benefits and risks have been examined in recent reviews [7–12], and an emerging literature suggests consumption of high-THC cannabis flowers is associated with greater severity of dependence [13] and adverse psychological outcomes [5, 14]. The proliferation of new high-THC products (e.g., "shatter") and methods of consumption (e.g., "dabbing"), particularly in jurisdictions allowing recreational and/or medical cannabis sales [15, 16], has raised additional questions, as their use and consequences have only recently begun to be examined [17–21], and it is difficult to predict how legalization will influence their demand [22, 23]. Further, there is no consensus about whether individuals who use products with higher concentrations of THC titrate their doses [24, 25].

There are also questions about the relationship between potency and price. Users report being willing to pay more for higher potency cannabis [26, 27], and there is a positive association between price and potency [28], but consumers in illegal markets for cannabis have only limited information about potency and quality. For instance, Ben Lakhdar [28] showed that although French consumers' perceptions of cannabis potency were positively associated with actual potency as assayed in the lab, there remained large gaps between perceived and actual potency. How all of this pertains to cannabis sold in legal markets is unknown, as characteristics of quality beyond potency, including contaminants, consistency, and freshness, are likely less variable in regulated legal markets than their illicit counterparts.

Events in the US allow an empirical investigation of potency and prices in legal cannabis markets since the states that allow cannabis sales for non-medical use neither discourage the consumption of high-potency products nor impose potency limits (except for edibles). This study examines the universe of cannabis purchases in Washington State's pioneering legal retail market.

In 2012, voters in Washington passed Initiative 502 which legalized cannabis possession and use for nonmedical purposes, and established a framework for state-licensed production, distribution, and sales, to be regulated by the Liquor and Cannabis Board (LCB). A traceability system was established to track inventory from seed-to-sale, and the first licensed retailer opened in July 2014. Transactions across market levels (i.e., from producers to processors to retailers) were each taxed at 25%, and additional state (6%) and local sales taxes applied at the point of purchase [29]. Effective July 2015, the tax scheme was changed to a single 37% excise tax at retail, in addition to state and local sales taxes as before. The medical cannabis industry, which had been operational since 1998, was folded into the recreational market effective July 1, 2016 [30, 31]. As of December 12, 2016, LCB had issued 467 licenses for retailers, 141 for processors, 917 for producer-processors, and 174 for producers [32].

To improve understanding of how cannabis legalization shapes product variety, potency, and prices, we used data from Washington's traceability system to analyze over 30 million cannabis purchases made between July 7, 2014 and September 30, 2016. The study aims were to: (1) assess trends and variation in the types and potency of cannabis products sold, and (2) estimate how potency, quantity discounts, and other factors influence cannabis flower prices in this market.

METHODS

Design

Retail sales data were obtained through Washington's cannabis traceability system, linked to additional product- and licensee-related information. After excluding observations with missing or non-positive price values (0.2%), the dataset included 44,482,176 rows, each identifying one line in the sales logs of 36,001,228 separate retail transactions that occurred between the first day of retail sales (July 7, 2014) and September 30, 2016. Each observation is akin to a single line on a cash register receipt, hereafter referred to as an "item" for brevity, although sometimes a few identical items appear on a single line indicating that a customer is buying multiple units of that item. Hence, these data are finer-grained than transaction-level data; one purchase (i.e., one payment event by the customer) can involve multiple items and thus generate multiple rows in this data set. For each observation, the dataset provides reported date of sale, item weight, THC and CBD content, retail price, product category, retail store address, and an identification number for the producer or processor responsible for creating the final product. Currently, the dataset does not provide information to distinguish sales made from stores with medical endorsements, or of partially tax-exempt marijuana products.

For our first aim, descriptive statistics and linear regressions were used to estimate variation and trends in product types and potency. Analyses of potency were restricted to two types of products: flowers and extracts for inhalation. "Flowers" refer to the traditional form of dried herbal cannabis. "Extracts for inhalation" include products either consisting of cannabis resin (“kief” or “hash”) or manufactured from extracted cannabinoids, including vaporizer cartridges and solid concentrate (“wax” or “shatter”). We focused on these product types because they comprise the vast majority of sales and, unlike with edibles, their potency characteristics are readily retrievable from the traceability data.

For our second aim, hedonic price regressions were used to determine how cannabis flower prices vary with product and market characteristics. This technique [33] has been employed in the valuation of agricultural products, beverages, real estate, and automobiles, among other items. The basic concept is that firms offer differentiated products to satisfy heterogeneous preferences of consumers. Each set of product attributes commands a different price based on consumers’ willingness to pay and the marginal cost of producing each characteristic. Price analysis was restricted to cannabis flower products as flower represents the largest share of the market, is a more homogeneous product category that can be well-characterized by measuring its weight and potency, and has been examined in previous literature.

Measures

Expenditures were measured in US dollars, inclusive of excise taxes but not state or local sales taxes. Trends in product variety were measured using monthly share of expenditures by product type or potency category.

The traceability system reports potency as measured via laboratory testing. THC concentration was calculated as the estimated total weight of THC after decarboxylation as a percent of total item weight (see Supplementary Appendix for details). Similarly, CBD concentration was measured as total weight of CBD as a percent of item weight.

It is worth noting that the integrity of Washington’s accredited cannabis testing laboratories has been challenged. There are anomalies in the data, incentives to produce results favorable to customers, and limited enforcement mechanisms. However, criticism has largely focused on testing for contaminants, not potency [34], and on edible products (which we exclude), for which testing is technically more difficult [35]. Further, in April 2016, LCB increased enforcement by issuing new rules for a proficiency testing program to hold labs accountable (effective August 2016) [36], and in May issued its first laboratory certification suspension [37]. Sensitivity analyses motivated by these concerns are provided in the Supplementary Appendix.

For the cannabis flower price analysis, the outcome measure is the item-level excise-tax-inclusive price per gram, calculated as the excise-tax-inclusive price divided by the quantity purchased in grams and log-transformed. Key predictors are item weight (measured in grams and log transformed), as well as the measures of THC and CBD concentration described above.

Additional covariates in the hedonic price regressions were constructed from the reported date of sale. These included separate indicator variables for whether a sale occurred a) within the first three months of a store’s operation to account for store opening discounts, b) on April 20th, widely recognized as a cannabis holiday, c) on the week prior to the cannabis holiday (April 14^{th} to 19^{th}), and d) after June 30, 2015 to account for the change in Washington's cannabis excise tax. All regressions also controlled for time effects through indicator variables for month, day of month, and day of week, as well as a 5^{th} order polynomial time trend.

Data Analysis

To address our first aim, trends in product variety and flower potency were assessed by calculating the monthly proportion of total excise-tax-inclusive market expenditures by product type or (among flower products) by THC category. We selected October 2014 as the baseline month for calculating market growth over time (through September 2016) to allow some degree of market stabilization after the first store opened in July of that year. We estimated whether there was a statistically significant linear association between market share and time using a regression model with year-month (e.g., October 2014, September 2014) treated as a continuous variable. To compare levels and variation of THC and CBD across cannabis flower and extracts, we examined histograms and descriptive statistics, and calculated means and coefficients of variation (CV), defined as the standard deviation divided by the mean.

To address our second aim, graphical evidence was presented to illustrate price variation for cannabis flower over time and across purchase quantities. Multivariate linear regression models were estimated at the item level to relate flower prices to potency and quantity, controlling for other store-level, producer-level, and time-level covariates. Observations with outlying price and quantity measures were trimmed to reduce skew in the data, thus our analysis may be conservative with respect to the extent of price dispersion. Table 1 provides descriptive statistics for our sample characteristics and the variables used in the regression analysis.

The regression models included the natural log of excise-tax-inclusive price per gram as the outcome, and log-transformed purchase weight, total THC concentration, and CBD concentration as key predictors. To account for potential time-invariant retail store or producer heterogeneity, we estimated additional specifications controlling for retail store fixed effects alone, producer fixed effects alone, and both retail store and producer fixed effects. Details of variables, sample specification, modeling strategy, and sensitivity analyses for our primary results are provided in the Supplementary Appendix.

For all price regressions, robust standard errors were clustered at the dispensary location level using the sandwich estimator to allow for non-independence of observations within a retail store [38]. The dataset was prepared using R version 3.3.1 software [39], and Stata/MP version 14.1 software [40] was used to implement all statistical analyses.

RESULTS

Product variety and potency

Washington's retail cannabis market has expanded rapidly (Figure 1), with excise-tax-inclusive sales in September 2016 reaching $98 million. The composition of products has also changed. While cannabis flower still accounts for two-thirds of expenditures, its market share has declined by 22.4% (linear trend $P<0.001$) relative to October 2014 (Table S2). Cannabis extracts for inhalation now compose over 21% of expenditures, an increase of 145.8% ($P<0.001$) relative to October 2014. Market share for other cannabis products (e.g., edibles, tinctures, and suppositories) also increased between October 2014 and September 2016, though this trend was not significant ($P=0.058$) and these products still only account for 12.1% of expenditures.

Figure 2A separately plots the distributions of THC composition for flowers and extracts using all years of available data. Compared to estimates from illicit cannabis markets [41–43], THC potency is strikingly high for flower (mean 20.6%) and extracts for inhalation (mean 68.7%). Potency is more variable for extracts, but only proportionally; the CV of THC content for both product forms is just over 0.2.

High-CBD forms of cannabis have attracted attention for their reputed medical properties [44], but they account for a tiny share of Washington's legal retail market. The distribution of CBD composition is highly skewed (Figure 2B); average CBD for flower products is 0.34%, and for extracts is 1.8%. Even after July 2016 (when sales of medical cannabis were restricted to licensed retailers included in this dataset), items with greater than 4% CBD and less than 1% THC accounted for just 0.14% of sales revenue in the markets for flower and extracts for inhalation.

Among flower products, the market share of strains with greater than 15% THC has grown to 92.5% of flower sales (Figure 3), and (not shown) an even greater share of THC consumption. Flowers with less than 10% THC now account for less than 2% of flower expenditures, and market share for flower products with 10–15% THC has significantly declined by 60.4% since October 2014 (linear trend $P=0.007$; see Table S2). In contrast, the market share of flower products with more than 20% THC has increased by 48.4% since October 2014, now accounting for 56.5% of retail expenditures on cannabis flower; however, this linear trend was not significant ($P=0.228$).

Price variation in the market for cannabis flower

Prices for flower in Washington have fallen sharply since the market opened (Figure 4), but there is substantial variation in prices around that trend that does not appear to be merely an artifact of the market's nascence. Indeed, since March 2015, the CV has remained relatively stable at around 0.3.

Some variation stems from quantity discounts, which have been studied in markets for illicit drugs [45–47]. Figure 5A presents box-whisker plots for the tax-inclusive price per gram separately by purchase size category. The corresponding plot for price per milligram of THC (Figure 5B) is similar as there is little variation in potency across item sizes. The plots suggest the existence of quantity discounts for purchases greater than 5 grams in weight, with larger discounts for purchases of about an ounce. Nevertheless, smaller transaction quantities dominate the market. Purchase sizes less than 5 grams in weight accounted for nearly 75% of all cannabis flower expenditures in 2016.

To more precisely characterize the determinants of price variation, Table 2 presents results from the hedonic price regressions. The coefficient on *ln(quantity)* can be interpreted as the size-elasticity of the per-gram price, which is a function of the product markup and the conversion factor that transforms some larger quantity to a smaller one [45]. Based on specification (iv), which includes both retail store and producer fixed effects, the estimated discount elasticity indicates that a 10% increase in the size of a transaction is associated with a 0.62% reduction in the unit price. In other words, consumers purchasing an eighth of an ounce (3.55 grams) of flower on average pay about 16% less on a per gram basis than do consumers purchasing one gram at a time.

All specifications show a statistically significant but small relationship between tax-inclusive price per gram and potency. Depending on the particular regression model and accounting for the 95% confidence intervals (CI), a one percentage point increase in THC (CBD) potency is associated with a 1–2% (1.5–2.5%) increase in price. Since THC potency averages about 20%, a roughly 5% increase in THC is associated with increases in price of less than 2%. Thus, the cost per unit of THC is lower for the more potent forms.

Prices are significantly discounted [coefficient = −0.30; CI = −0.35 to −0.27] on April 20th, and there is evidence of smaller but significant price reductions in the week leading up to April 20th [coefficient = −0.02; CI = −0.03 to −0.01]. In model (iv) that accounts for both producer and retailer heterogeneity, the included variables explain approximately 54% of the observed variation in tax-inclusive price per gram of cannabis flower.

DISCUSSION

Washington's legal cannabis market has trended toward higher-THC products, as flower products with THC concentration over 20% and extract products with over 60% THC are now commonplace. By comparison, national estimates of average THC level for cannabis seized during prohibition did not exceed 5% in the US until 2001 [48], and as recently as 2010 typically ranged from 8% to 13% [41, 42]. Potency in Washington State also generally exceeds the 15% limit for cannabis products that has been discussed in the Netherlands [49]. In 2015, the strongest *Nederwiet* sold in Dutch coffeeshops averaged 17% THC (± 3.4%; [43]).

This directly contradicts Cowan's [50] so-called "Iron Law of Prohibition" which asserts that tougher enforcement drives up potency, and legalization would necessarily lead to less-potent drugs. As previously observed [51], the actual experience with cannabis liberalization's effect on potency has proved to be very different than that predicted by analysis of alcohol prohibition and drug markets under prohibition [52, 53].

The growing popularity of extract products in Washington's retail market is consistent with other research using data from social media [15, 16], and may reflect both supply-side and demand-side factors. Lower enforcement risks for suppliers have increased innovation of more advanced methods of extraction, as well as provided greater access to the raw inputs needed to produce concentrates [54]. Demand for alternatives to smoked cannabis may also be a factor, as exploratory studies have indicated a growing perception that vaporizing is a healthier and more efficient method of consumption than is smoking [55–57], analogous to perceptions that electronic nicotine delivery systems are less harmful than cigarettes [58]. However, there is concern about the increased consumption of extracts, as their potential health consequences are largely unknown [59].

Prices fell sharply after the opening of legal retail stores as new retailers entered the market and production expanded. The coefficient of variation for prices has stabilized at around 0.3. This suggests much less price variability than what Reuter & Caulkins [60] observed for U.S. cocaine and heroin markets, and much greater variability than that found for most conventional goods [61] or groceries [62]. It is also greater than the price variability observed in California for beer (0.19) or spirits (0.24), but slightly lower than for wine (0.34) [63].

Our estimated quantity discount elasticity of −0.06 is much smaller than estimates for the illicit market in the United States, which ranged between −0.15 and −0.57 [45, 64], or Australia, which ranged between −0.2 and −0.3 [46, 65]. There are a number of potential explanations. For one, potency has largely been excluded from prior models due to data limitations. If in those data sets smaller purchases had higher average potency (e.g., because low potency commercial grade material was sold by the ounce not by the gram), then omitted variable bias would lead past estimates to overstate quantity discounts. While our data do not suggest that there is a tendency for larger items to have lower THC content (Figure S1), illicit markets may differ in this regard. Additionally, our analysis pertained only to retail purchases, which Washington's law restricts to no more than one ounce; future analyses of wholesale transactions within the traceability data may show larger quantity discounts between wholesale and retail quantities.

Another explanation recognizes that quantity discounts are the flip side of price markups, which in a competitive market generally reflect the costs of distributing drugs. If legalization lowers the risks and other costs of distributing cannabis, then that would naturally produce lower markups and, hence, smaller quantity discounts. Overall, our findings do not indicate that retailers are offering significant incentives for consumers to make larger purchases.

Our findings are consistent with product innovation, product development, and marketing investments characteristic of the profit-oriented marijuana industry established by Washington's legal framework [66]. The consequences of smaller price markups and higher potency remain to be seen. Washington is allowing the potency and price of legal cannabis to be shaped by the market; remember, this is a choice [67]. Potential policy levers for controlling potency include potency-driven taxes, price floors linked to potency, or THC limits. Although these may be challenging to enforce and no evidence exists yet on what threshold constitutes a "safe" potency, risk-averse jurisdictions considering or implementing nonmedical legalization may nonetheless want to discourage consumption of high-potency products until more is learned about their health effects.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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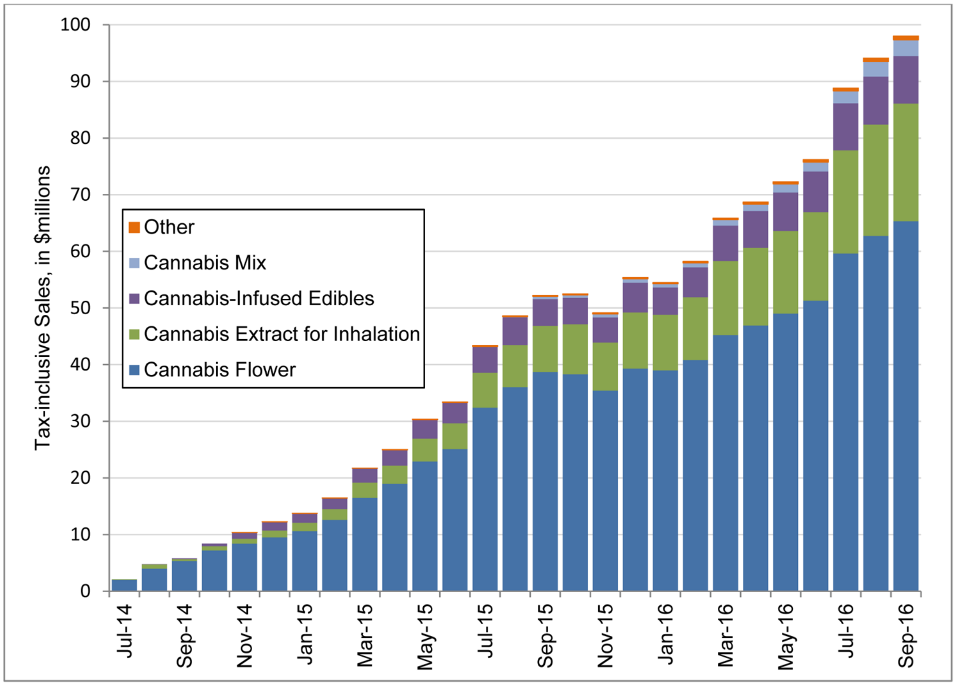

Figure 1. Trends in Product Sales

Notes: "Cannabis-Infused Edibles" contains both solids and liquids. "Cannabis Mix" includes products that mix several types of cannabis together, such as flower cured in kief. The "Other" product category combines tinctures, capsules, suppositories, and cannabis-infused topicals.

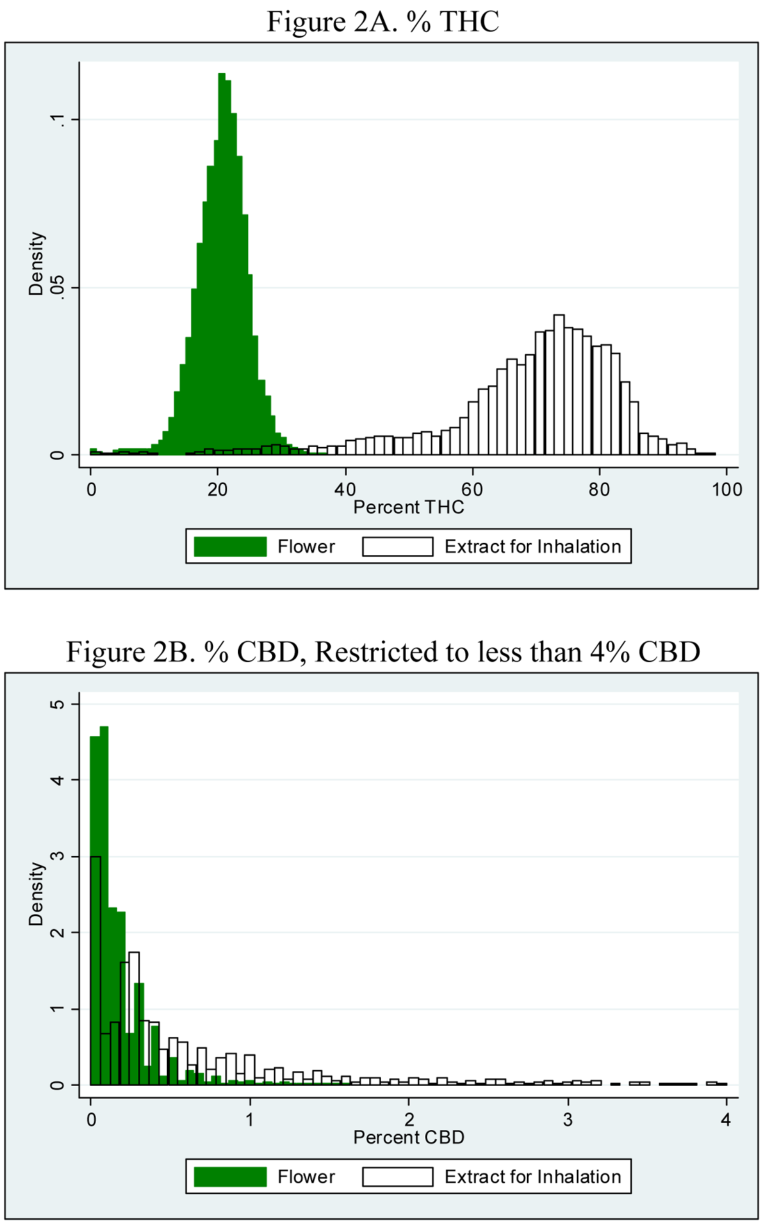

Figure 2. Distribution of THC & CBD in flower and inhalation extract purchases

Notes: For Figure 2B, restricting to observations with CBD concentration less than or equal to 4% preserves 98.6% of all flower observations and 93.9% of all extract observations.

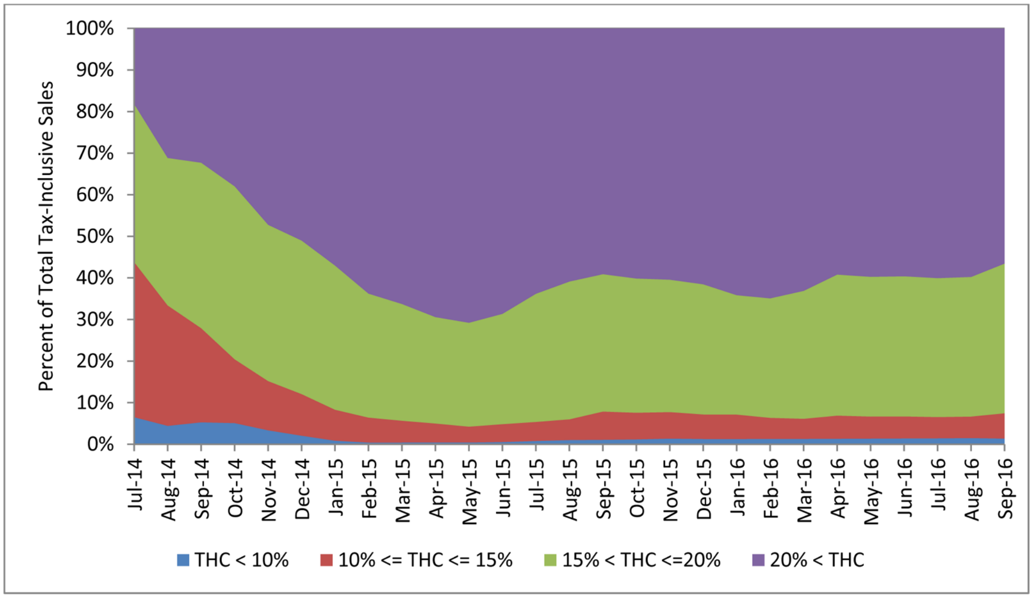

Figure 3. Market shares for cannabis flower products sold, by THC% Category

Notes: Market share is calculated as a percent of total cannabis flower expenditures (excise-tax-inclusive).

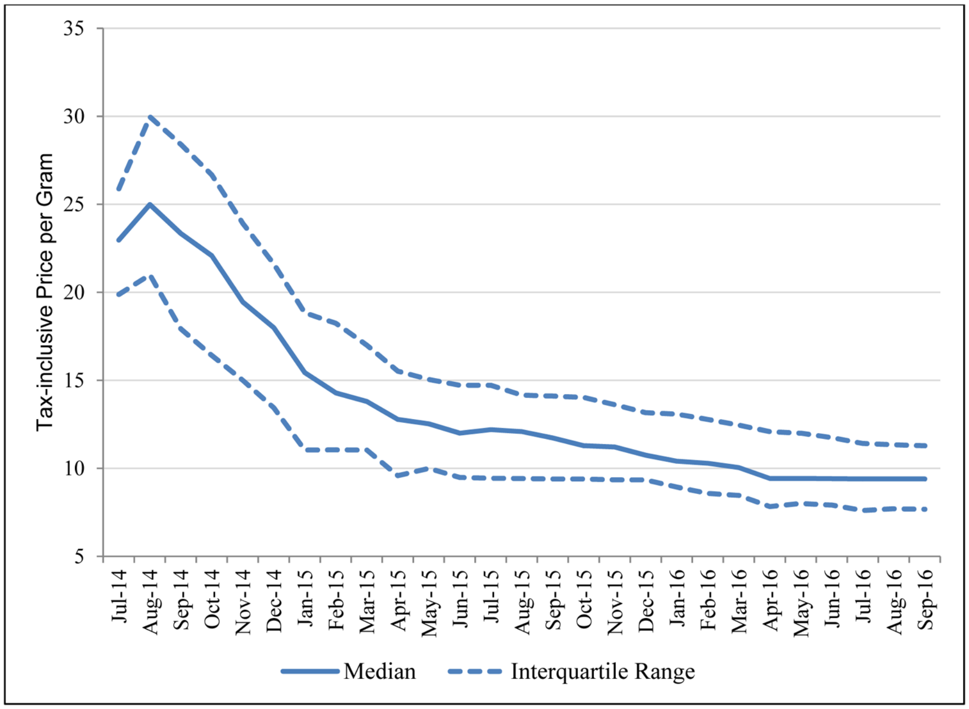

Figure 4. Trends in Median Price per Gram and Price Variation for Cannabis Flower

Notes: Dashed lines represent the 25^{th} and 75^{th} percentiles.

Figure 5A. Variation in tax-inclusive price per gram

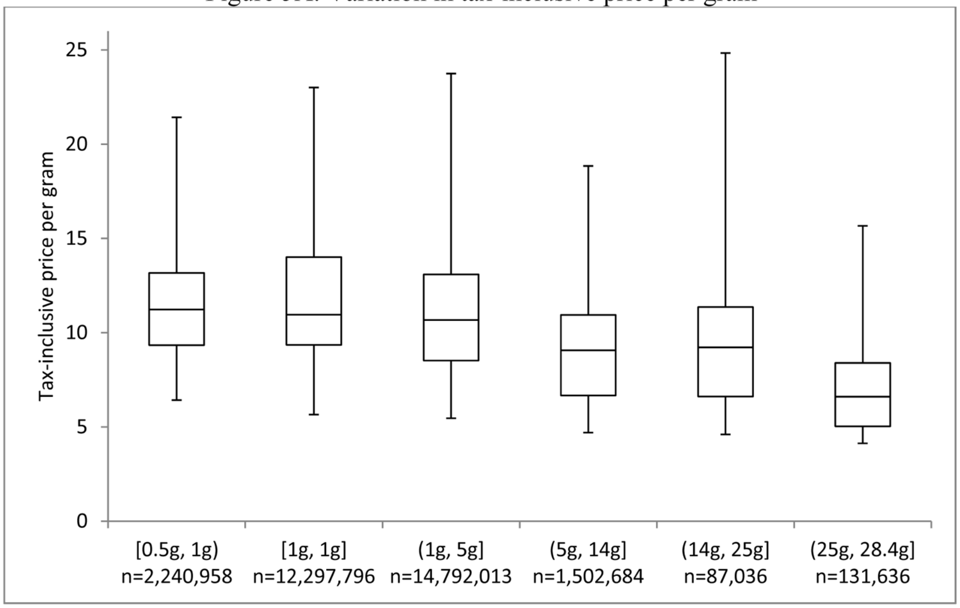

Figure 5B. Variation in tax-inclusive price per mg THC

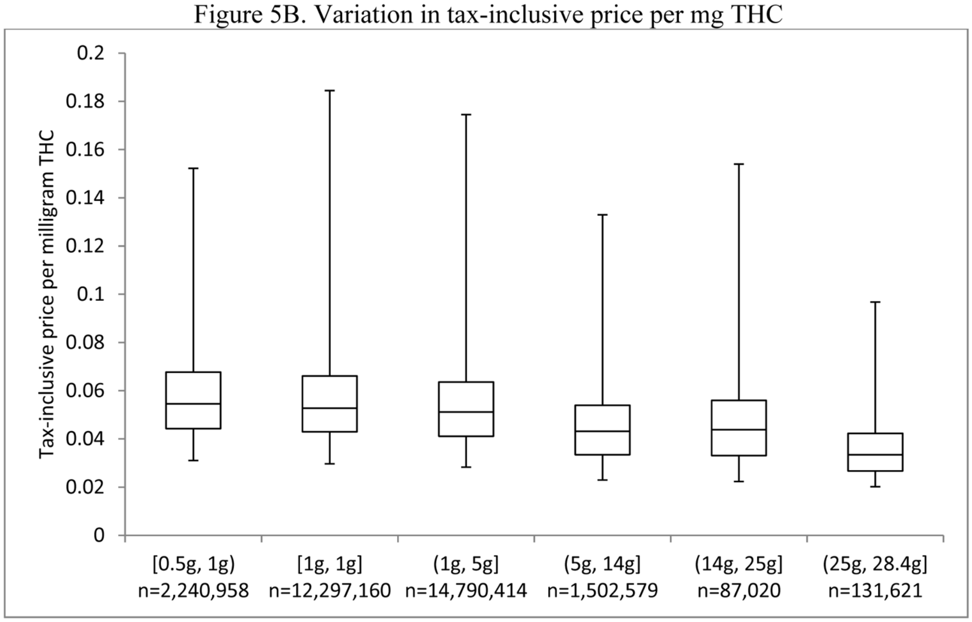

Figure 5. Variation in tax-inclusive price of cannabis flower, by usable weight category

Notes: Whiskers extend from 1st to 99th percentile. Boxes represent the interquartile range segmented by median price. Disagreements in observations across Figure 5a and 5b are due to a small number of observations reported to have 0 THC.

Table 1

Descriptive statistics for cannabis flower purchases

	Mean	Standard Deviation	Minimum	Maximum
	Full Sample with Positive Price and Valid Potency (n=31,737,625)			
Price per gram ($, tax-inclusive)	11.15	13.403	0.000	6000.00
THC (%)	20.59	4.185	0.000	65.80
CBD (%)	0.340	1.344	0.000	26.10
Usable weight (grams)	2.423	6.550	0.003	2272.7
April 20	0.006	0.077	0	1
April 14–19	0.022	0.148	0	1
Open < 3 months	0.096	0.295	0	1
Post tax change	0.868	0.338	0	1
	Sample after Trimming Price and Quantity Outliers (n=31,052,123)			
Price per gram ($, tax-inclusive)	11.06	3.799	2.82	60.08
THC (%)	20.58	4.151	0.000	65.80
CBD (%)	0.338	1.336	0.000	26.10
Usable weight (grams)	2.255	2.673	0.500	28.40
April 20	0.006	0.076	0	1
April 14–19	0.022	0.147	0	1
Open < 3 months	0.096	0.295	0	1
Post tax change	0.869	0.338	0	1

Notes: Exclusion of quantity and price outliers is explained in the text, with further detail in the Supplementary Appendix.

Table 2

Explaining Variation in Price per Gram of Flower

	Dependent variable: Ln(Tax-inclusive Price per Gram)			
	(i)	**(ii)**	**(iii)**	**(iv)**
THC (%)	0.018*** (0.016,0.020)	0.018*** (0.016,0.020)	0.012*** (0.011,0.013)	0.012*** (0.011,0.013)
CBD (%)	0.021*** (0.018,0.024)	0.021*** (0.018,0.024)	0.017*** (0.015,0.019)	0.017*** (0.015,0.019)
ln(quantity)	−0.082*** (−0.095, −0.068)	−0.069*** (−0.078, −0.059)	−0.070*** (−0.041,0.003)	−0.062*** (−0.071, −0.054)
Store open < 3 months	−0.018 (−0.045,0.010)	−0.014 (−0.032,0.004)	−0.019 (−0.041,0.003)	−0.020* (−0.036, −0.004)
Post-tax change	0.026* (0.003,0.049)	0.030** (0.009,0.050)	0.019 (−0.000,0.038)	0.020* (0.002,0.038)
April 20	−0.318*** (−0.354, −0.282)	−0.315*** (−0.350, −0.281)	−0.314*** (−0.354, −0.273)	−0.312*** (−0.352, −0.272)
April 14–19	−0.023*** (−0.037, −0.009)	−0.022** (−0.037, −0.009)	−0.024*** (−0.036, −0.012)	−0.022*** (−0.034, −0.009)
Adjusted R-squared	0.27	0.38	0.47	0.54
Month fixed effects	Y	Y	Y	Y
Day of month fixed effects	Y	Y	Y	Y
Day of week fixed effects	Y	Y	Y	Y
Time trend (5^{th} order polynomial)	Y	Y	Y	Y
Retailer fixed effects	N	Y	N	Y
Producer fixed effects	N	N	Y	Y
Number of observations	31,052,123	31,052,123	31,052,123	31,052,123
Number of retailers	335	335	335	335
Number of producers	682	682	682	682

Notes:

* p<0.05,

** p<0.01,

*** p<0.001.

All specifications include month, day of month, and day of week fixed effects, and a 5^{th} order polynomial time trend. Column (ii) adds retail store fixed effects, Column (iii) replaces retail store fixed effects with producer fixed effects, and Column (iv) includes both retail store and producer fixed effects. Robust standard errors are clustered at the retail store level, and 95% confidence intervals are provided in parentheses.